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Mulch amendment facilitates early revegetation development on an abandoned field In northern mixed grass prairies of North America

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ABSTRACT

Extensive areas of the northern mixed grass prairies of North America require restoration and reclamation as they have been extensively disturbed by agricultural, mining and oil and gas related activities. Amending seedbeds with mulch may avoid soil erosion and help both plant recruitment and early vegetation development in these water limited landscapes. A field experiment was established to determine if straw and hay mulch facilitate early revegetation. The site is an abandoned irrigation area in southern Alberta, Canada. Soil was tilled and the seedbed prepared through manual harrowing, then plots were broadcast seeded with *Elymus trachycaulus*, *Bouteloua gracilis*, *Astragalus canadensis* and *Linum lewisii*. Hay and straw mulch were applied at two rates (300 and 600 g m^{-2}). Plant recruitment and cover were assessed through the first four years. Mulch had a positive impact on recruitment of all species planted except *Bouteloua gracilis.* While a thinner material like hay proved to be most effective at high rates (600 g m^{-2}), a thicker material like straw encouraged quick recruitment for these species only at low application rates (300 g m^{-2}). However, these early differences among mulch treatments did not show an impact in either recruitment or cover during subsequent years. *Bouteloua gracilis*, whose recruitment and growth were broadly impaired by mulch, showed an abundant and constantly increasing cover in the bare ground control and in plots with low application rates of hay. Both recruitment and cover per species indicate that plots are following two different trajectories that show some degree of resilience; the bare ground treatment is dominated by *Bouteloua gracilis* whereas the mulch treatments are characterized by vegetation dominated by *Elymus trachycaulus, Linum lewisii* and *Astragalus canadensis*.

1. Introduction

Northern mixed grass prairies of North America have been extensively disturbed through cropping and oil and gas extraction activities. Disturbances include the complete loss of vegetation and deep soil perturbations such as soil horizon admixing, soil compaction and soil contamination. Denuded dry mixed grass prairies are prone to erosion and encroachment of invasive species, so rapid plant cover is highly recommended (Kerr et al., 1993). Land use in the region is partitioned between crop production under irrigation or rainfed rangeland grazing, the latter more environmentally friendly than the former. Thus establishment of native vegetation resembling that of a natural prairie is a popular reclamation option as it satisfies requirements for attaining equivalent land capability linked to a positive impact on public opinion. However, a spontaneous return to native range conditions after disturbance is slow in the northern mixed grass prairies (Dormaar and Smoliak, 1985), making it critical to develop revegetation techniques to accelerate the process.

Successful revegetation in semi-arid grasslands is a challenge as water availability strongly limits plant establishment, growth and survival. The mixed grass prairies are characterized by their variability and deficiency in precipitation during the growing season (Coupland, 1992) so any measure to conserve soil water may have positive effects on revegetation. Practitioners have envisioned the use of surficial amendments with straw and hay as a way to control water and wind erosion and to improve the soil water balance during reclamation (Kerr et al., 1993; Fehmi and Kong, 2012). Surficial amendments can also improve germination rates of broadcast seeds (Mollard and Naeth, 2014), particularly on those grassland species whose seeds are photo-inhibited; thus germina-

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tion is encouraged on covered soils relative to bare soils (Baskin and Baskin, 1998, 2014; Mollard and Naeth, 2014). However, uncertainties about mulch effects on vegetation arise due to the lack of well documented scientific research for the region. Due to their similar nature, it is possible to draw a parallelism between straw or hay mulch and litter, with the purpose to overcome the scarce mulch research and use patterns found from litter research in the northern mixed grass prairies.

The importance of the effects of litter on structure and function of mixed grass prairies has been highlighted through litter manipulation experiments (Willms et al., 1986; Naeth et al., 1991; Deutsch et al., 2010). That knowledge can be used to anticipate possible outcomes of the effects of mulch types and rates on seedling emergence and establishment and on performance of adult plants. Litter has a significant effect on microclimate near the ground surface and plays a main role in the surface–atmosphere energy and water exchange (Facelli and Pickett, 1991). High litter amounts improve soil water content and stabilize plant production, providing an important drought management strategy in northern prairies (Willms et al., 1986, 1993; Deutsch et al., 2010). Those results justify the use of mulch as a revegetation technique; however, abundant litter may intercept rainfall and affect water available for infiltration (Naeth et al., 1991).

Despite the positive effects of litter on plant productivity and range value (Willms et al., 1986, 1993; Deutsch et al., 2010), its effects on plant performance and on development of a diverse prairie vegetation are not clear. Litter may have a positive effect on seedling survival and establishment by improving soil water balance or attenuating soil maximum temperatures; or negative effects due to its high mechanical impedance and the increase in the path a seedling needs to penetrate during emergence (Facelli and Pickett, 1991). Meta analyses of global data have shown that litter usually has neutral to inhibitory effects on seedling establishment and on plant diversity, especially at high quantities (Xiong and Nilsson, 1999; Loydi et al., 2013). In the aspen parkland prairies, litter has a negative influence on diversity by reducing plant richness (Lamb, 2008) and dense litter accumulation in temperate grasslands can affect plant growth and development, so plants grow more slowly and flower more sparsely due to lower soil temperatures (Weaver and Rowland, 1952). This background suggests that litter quantity is a main driver of plant and vegetation responses. Therefore, we hypothesized that both mulch application rate and texture would affect plant performance which prompted us to evaluate two mulch materials, cereal straw and hay, at two contrasting amendment rates for grassland restoration.

A manipulative experiment in the northern mixed grass prairies of southern Alberta showed that mulch improved seedbed environmental conditions and increased seedling emergence during the first year of prairie revegetation (Mollard et al., 2014). That experiment, on an abandoned irrigated crop field, showed that the effect of mulch on plant establishment varied from facilitative to inhibitory depending on mulch texture (hay vs. straw) and amendment rates as high straw rates hindered plant recruitment (Mollard et al., 2014). In this paper we continue the above mentioned research during the first four years of reclamation to determine if straw and hay mulch at different rates accelerated native plant species revegetation in northern mixed grass prairie.

2. Materials and methods

2.1. Experimental site

The experimental site is situated on the Rangelands Research Institute of the University of Alberta in the Dry Mixed Grass Prairie Ecozone of southern Alberta (50°53′30.7″ N, 111°56′52.1″ W), Canada. Natural vegetation is dominated by *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama grass), *Hesperostipa comata* Trin. & Rupr. (needle and thread grass)) and *Koeleria macrantha* (Ledeb.) Schultes (june grass) (Strong and Leggat, 1992). The climate is continental, sub-humid, characterized by long cold winters and short summers. Mean July and January daily temperatures of the region are 18.3 and −11.3 °C, respectively (Environment Canada, 2016). Mean annual precipitation in the region is 348 mm, two thirds occurring during the growing season (Environment Canada, 2016; Kjearsgaard et al., 1983). Potential evapotranspiration deficit during the growing season exceeds 100 mm (Strong and Leggat, 1992). Elevation is 720 m above sea level. The landscape is rolling with fluvial-eolian loamy sand surficial deposits (Kjearsgaard et al., 1983). Topsoil is well drained, sandy to loamy sand texture, with a sand content of 87%, an organic matter content of 1.2% and a pH of 6.45 (Naeth et al., submitted manuscript).

Research was conducted in an old abandoned irrigation field which was seeded with *Bromus inermis* Leyss. (smooth brome) after agricultural use. Established vegetation was dominated by *Bromus inermis*, *Calamovilfa longifolia* (Hook.) Scribn. (prairie sand reed) and *Artemisia frigida* Willd (pasture sage). The land is used as cattle range on a rotational grazing basis.

2.2. Soil preparation, seeding and mulch treatments

On May 15, 2012, a 0.36 ha (65 × 55 m) site was sprayed with glyphosate (Roundup Transorb, Monsanto, St. Louis, MO, USA) at a rate of 8 l/ha, rototilled to a depth of 15 cm 10 days later, and fenced to prevent cattle and wildlife grazing. Six replicate 2 × 2 m plots per treatment were hand raked to remove dead plant material and to prepare a smooth seedbed.

Certified seeds purchased from local suppliers were used in the experiment. Pure seed units were selected by diaphanoscopy. These pure seeds units consisted of intact natural dispersal units (caryopses, one seeded florets or seeds, hereafter referred as seeds). Seeded species were: *Hesperostipa comata* (Trin. & Rupr.) Barkworth (Syn = *Stipa comata* Trin. & Rupr. (needle and thread grass), *Elymus trachycaulus* (Link) Gould ex Shinners *ssp. trachycaulus* (Syn = *Agropyron trachycaulus* (Link) Malt. (slender wheat grass)), *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths var. Bad River (blue grama grass), *Astragalus canadensis* L. var. ARC Aspen (Canada milkvetch) and *Linum lewisii* Pursh (wild blue flax). Plots were hand seeded on June 8 2012. Fifty seeds per species were carefully spread in a core area of 1 × 1 m centered in the 2 × 2 m treatment plots. The area outside the core worked as an area for soil monitoring, sampling and plant measurements. In this area seeds were weighted to get a target rate of 50 PLS per m^2 and species before seeding.

The experiment assessed two mulching materials commonly used for reclamation, wheat straw and rangeland hay. Different mulching properties were expected between these two materials due to coarser texture of straw (mostly wheat culms approximately 30 cm long and 0.5 cm in diameter) and finer texture of native hay (mostly thinner grass culms and leaves). The experiment followed a randomized single factor design with a bare ground control. Mulch treatments were: high hay rate, low hay rate, high straw rate, low straw rate and bare ground (control). Hay and straw were applied at rates of 300 (low) and 600 (high) g m^{-2}, considered appropriate for grassland revegetation (Kiehl et al., 2006; Kiehl and Wagner, 2006). On June 6, 2012, fresh native hay was mechanically mowed in a nearby field and harvested two days later (seeding day). Hay was composed of grass and forb plant material (green and dead leaves, vegetative stems with no previous year standing inflorescences). The surface layers of one year old wheat straw bales were used for straw mulch. Water content of the native hay and wheat straw was 8 and 7%, respectively, determined after oven drying at 90 °C to constant weight. Plots were covered with open mesh plas-